Effectiveness of a newly constructed wetland on agricultural run-off

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Introduction

Excess of nutrient due to the extensive use of chemical fertilizers in agriculture can be mediated by the creation of wetland systems as buffer zones (Comin et al., 1997; Reed et al., 1988). These functions of wetland systems are especially attractive as crop output in the United State has been augmented by an increasing reliance on commercial fertilizers to maximize yields and pesticides-herbicides to control pests and weeds. Farmers also tend to over-fertilize their fields to assure that nutrient levels are not a limiting factor in good weather years (Tonderski, 1996). Such intensified farming practices accounted for 98% of the food production increase that has occurred over the last thirty years in the industrialized nations (WDR, 1992). It is estimated that 50-70 percent of all nutrients that reach surface waters originate on agricultural land (Jahn and Schenck, 1991).

Because of the high quantities of phosphorus and nitrogen in most crop-lands, the ability of wetlands to retain these nutrients is particularly important in the agricultural setting (Vaithiyanathan and Correl, 1992). The major phosphorus storage pools in a wetland system are the litter and sediment (Richardson and Marshall, 1986). Most wetlands are effective sinks only at low phosphorus loading rates and at low hydraulic flow rates. If the phosphorus input rate exceeds the long-term sink capacity, the wetland will eventually act as a downstream source (Richardson et al., 1997). Wetlands that experience frequent drawdowns, whether by natural or artificial processes, also are known to release sorbed phosphorus (Olila et al., 1997). Drawdowns, however, can lead to an increased consolidation of newly deposited materials and an increase in the rate of new soil build-up (Coveny et al., 1994). The primary form of mineralized nitrogen in most flooded wetland soils is the ammonium ion. The ammonium-nitrogen is oxidized (nitrification) in a thin layer present at the soil surface of most wetlands or in the oxidized rhizospheres of plants into nitrate-nitrite. The nitrate ion (NO_3-) is not prone to immobilization by soil particles, as it is negatively charged. Rather, nitrate is removed from the water column by direct plant assimilation, reduction to ammonia, or conversion to N_2O or N_2 gas (denitrification).

It is evident therefore that a balance between wetland design and management techniques must be achieved in order to maximize the effectiveness of the wetland's nutrient retention capabilities. This case study examines the effectiveness of a small newly constructed wetland to change water quality, particularly with regards to nitrogen and phosphorus. To achieve this objective, both the change in water chemistry and the hydrology of the wetland were examined.

Methods

Site Description

The Indian Lake Watershed Project wetland was constructed in the spring of 1998 in Rush Creek Township, Logan County, Ohio, USA adjacent to a tributary of the South Fork of the Great Miami River. Indian Lake Wetland is a 1.2 ha basin containing five separate permanent and seasonal small ponds linked by surface and subsurface flows (Figure 1). The total surface area of the ponds is approximately 0.2 ha. The wetland drains a single 17 ha watershed, of which 14.2 ha is used for intensive row-crop agriculture and 2.8 ha is forested (Figure 2). This gives a wetland to watershed ratio of 1:14. Surface water comes into a receiving pond (Pond 1) down a rock lined spillway and through direct overland inflows from the elevated farmed hills. The design of the wetland is such that the water subsequently flows through each of the other ponds on its way through the wetland basin and out to the river. There are several groundwater discharge areas along the wetland boundary. One of these seeps is located on the northern end of Pond 3 (Figure 1). A second seep is located inside the 'curl' on the southwest side of Pond 4 (Figure 1). Most of the outflow from the wetland leaves from the northern edge of Pond 4 and enters the river down a grassy spillway, netted to reduce erosion, or through an outflow pipe in the levee on the west side of the wetland basin. The soil types that comprise the watershed and wetland area are primarily St. Clair and Lippincott. Both of the these soil types can have hydric characteristics.

Surface Hydrology- Precipitation, Evaporation, and Outflow

Staff gauges were installed in December 1998 in each of the five ponds, and beneath the bridge where State Route 68 crosses the river (Figure 1). Two rain gauges were also installed in December 1998. Rain Gauge 1 was placed on the levee separating Pond 1 from the rest of the wetland

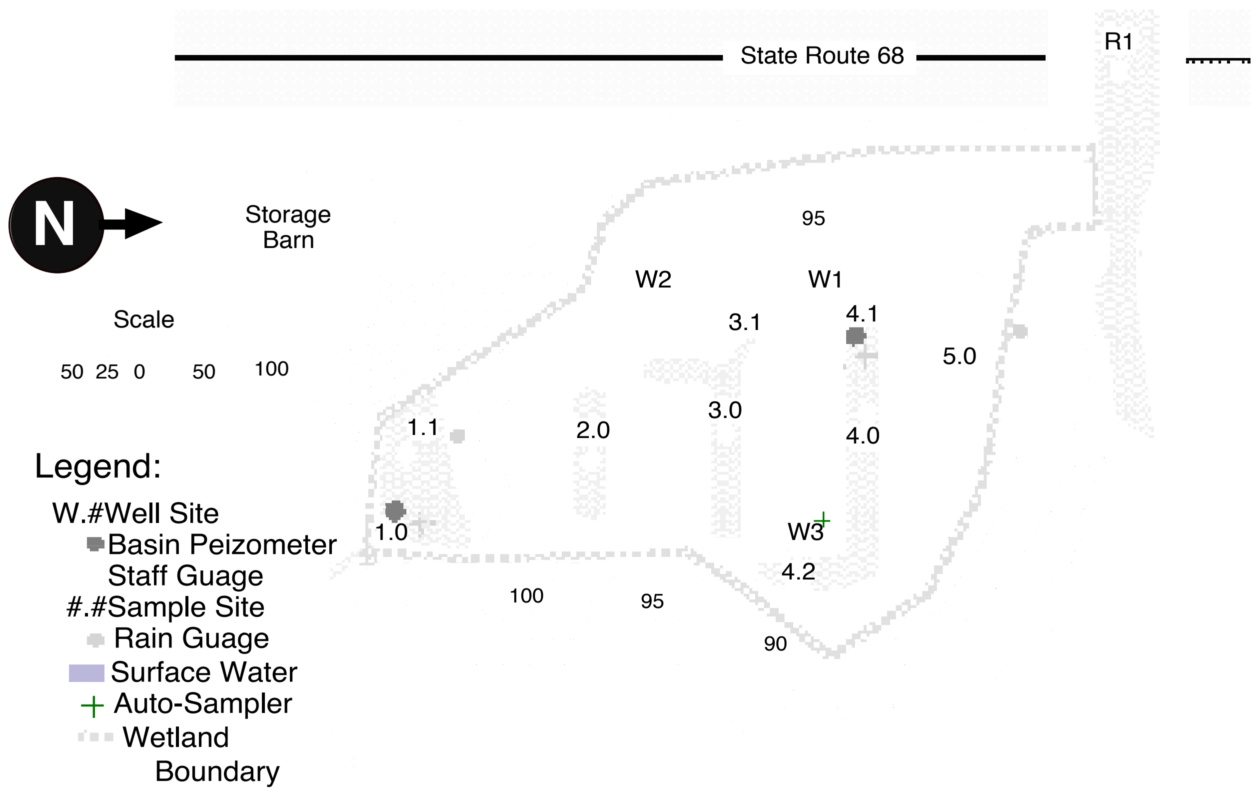

Figure 1. Site map and the location of sampling stations and hydrology observation devices in the Indian Lake Demonstration Wetland.

basin and Rain Gauge 2 on the levee separating Pond 5 from the river (Figure 1). To prevent evaporation in the spring and summer months, 0.25 cm of vegetable oil was added to the rain gauges. To prevent freezing during the winter, 0.25 cm of antifreeze was added to the rain gauges.

Groundwater Hydrology

Three shallow wells were installed in March 1999 (Figures 1 and 3). The wells are 3.18 cm (1.25 inches) diameter galvanized steel well points with 80 mm stainless steel screens that extend over the lowest 76 cm of the well casing. All well screens are between two and three meters deep. The wells were hand dug with a post hole digger to a depth of one meter, then driven the remaining required depth with a sledge hammer. A 30 cm deep layer of bentonite was packed around the well casing above the screen. The remaining depth was then back-filled with the soil extracted by the post-hole digger. Back-fill was also mounded 10 cm around the base of the well casing. The back-fill and the bentonite prevent ‘stem flow’ along the well casing from reaching the screened portion of the well.

A well was installed adjacent to groundwater discharge points near the south west end of Pond 4 and the north end of Pond 3 to asses water quality and to determine the hydraulic conductivity of the substrate (Figure 1). The water level in the wells was determined using a Solinst 101-50 P2 electric water level monitoring probe down the well casing. The probe has an accuracy of +/- 0.24 cm (0.05 ft).

Sample Collection

Twice per-month water sampling was begun late October 1998 and continued through December 1999. Surface water samples were taken from nine locations (Figure 1). Samples were collected at each of the nine locations in a 500 ml polyethylene bottle that was acid washed with a 50% HCl acid solution and triple rinsed with distilled water. A YSI Incorporated 600 XL-B-M multi-probe was also used to measure temperature, dissolved oxygen, conductivity, pH, and redox potential at each of these locations. A 500 ml groundwater sample was collected from each of the three wells, after their installation in the spring of 1999, through tygon tubing which was flushed prior to use with distilled water to remove contaminants.

Sample Analysis

Samples were taken to the lab where 125 ml subsamples were filtered through 0.45 mm Osmonics nitrocellulose disc filter for analysis of nitrate-nitrite (NO_3 + N_2O). Unfiltered 125 ml subsamples were preserved with concentrated H_2SO_4 (2 ml/liter sample) for total phosphorus and soluble reactive phosphorus (SRP) analyses. Sample preparation and preservation occurred within 48 hours of collection.

The Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA, 1998) and the EPA Methods for Chemical Analysis of Water and Wastes (U.S. EPA, 1993) were followed for all laboratory analysis. Total phosphorus and soluble reactive phosphorus were analyzed using an ascorbic acid and a molybdate color reagent method. Nitrate-Nitrite was measured using a Cadmium Reduction Flow Injection Method.

Results

(Nitrate-Nitrite-N) Retention

The seasonal pattern of nitrate-nitrite concentration in the Indian Lake Wetland is shown in Figure 4. There were several major nutrient pulses throughout the year following large rain showers in early February (this was coupled with the melting of the existent snow cover), April, mid-June, and late September (Figure 5). During these larger pulses, the export of nitrate/nitrite increases proportionately to its import, but the wetland still tended to act as a sink. It is interesting to note that in most cases the peak nutrient outflow was offset from the nutrient inflow by approximately 15 days.

Nitrate-Nitrite decreased on average by 30% in 1999. This reduction, however, was not linear across the flow path of the wetland (Figure 6a). Most of the noticeable nutrient loss had occurred by the time the flow left Pond 2. Additional loss occurred as the flow path proceded through the Pond 3 and Pond 4 areas of the wetland, but these were less noticeable as each of these ponds also received additional nutrient inflows from the ground water seeps adjacent to site 3.1 and between sites 4.2 and 4.0.

Orthophosphate (SRP) Retention

The seasonal pattern of SRP concentration is shown in Figure 7. There were several major pulses of nutrient flow that occurred during the same time frame as for the nitrate/nitrite. During most of these pulses, the nutrient outflow exceeded the nutrient inflow. The only pulse in which the inflow SRP concentration remained greater than the outflow concentration was during the pulse associated with the combined rain and snow melt event in early February. Unlike the nitrate-nitrite pulses, however, a 15 day offset between the import and export of SRP was not noticed. The SRP concentration was reduced, on average, by 62% in 1999. This reduction was not constant across the flow path of the wetland (Figure 6b). The SRP decreased through Pond 3, and then increased in Pond 4. The reason for this increase was that the groundwater discharge between sites 4.2 and 4.0 contained almost three times as much SRP per liter as the wetland concentration of SRP in Pond 3.

Total Phosphorus

The seasonal pattern of the Total Phosphorus concentration in the wetland is shown in Figure 8. The same nutrient pulses existed for the total phosphorus as did for nitrate/nitrite and the SRP. In this case, the concentration of total phosphorus in the wetland outflow exceeded the amount in the wetland inflow during these high flow events. As with the SRP case, there was no discernible offset from the inflow to the outflow in terms of total phosphorus concentration levels.

The total phosphorus concentration on average was reduced by 37% in 1999. This reduction occurred in several steps across the flow path of the wetland (Figure 6c). The majority of the decrease took place by the time the flow passed through Pond 2. There was then a linear decease along the flow path through site 4.2. There was then an increase in the concentration of total phosphorus throughout the rest of Pond 4 as a result of the influx from the ground water discharge.

Dissolved Oxygen

The average dissolved oxygen level in the wetland was 10.25 mg/L and did not vary significantly from the inflow to the outflow of the wetland (a = 0.05). The only significant increase in the dissolved oxygen content was at site 3.1 which was, on average, 44% (15.07 mg/L overall average) greater than the rest of the wetland.

Temperature

Overall there was no significant average difference in temperature between the inflow and the outflow. There was only one location that had a consistently different temperature. Due to groundwater discharge, site 3.1 was warmer in the winter months and colder in the summer months than the rest of the openwater area of the wetland.

Conductivity

The average conductivity increased from 290 mS/cm at the inflow to 434 mS/cm at the outflow of the wetland for an average increase of 58%. This difference was highly significant (a= 0.05). This increase is likely due to a couple factors. The first is that much of the wetland is subterranean, so the water flows are likely to pick up dissolved ions as they move through the wetland. The second is that site 3.1 receives a ground water discharge that has a very high conductivity (774 mS/cm on average), which also serves to add dissolved ions to the water in the wetland.

pH

The pH of the inflow averaged 8.42 and the outflow

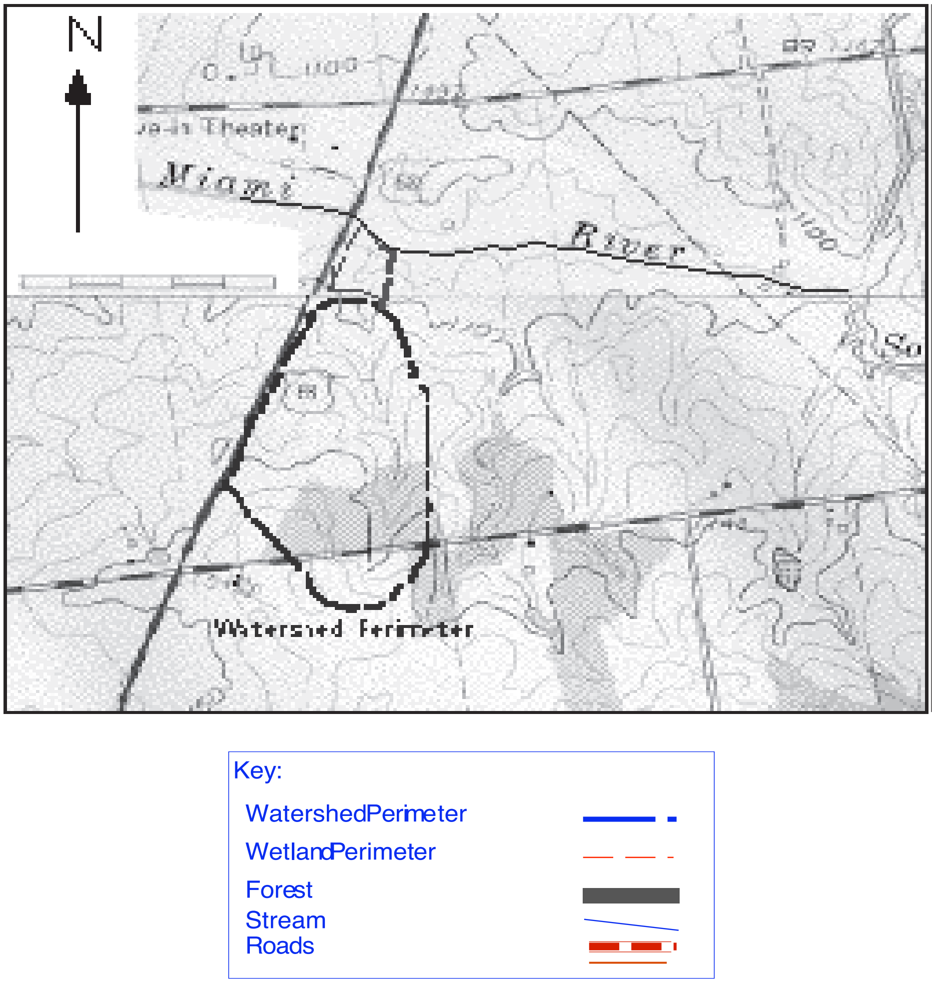

Figure 2. Watershed map of the Indian Lake Demonstration Wetland.

averaged 8.39 in 1999. There was no significant difference between the inflow and outflow (a= 0.05).

Redox Potential

There was a small but significant decrease in the redox potential from the inflow to the outflow of the wetland (a= 0.05), with the yearly averages being 209 mV and 196 mV respectively.

Discussion

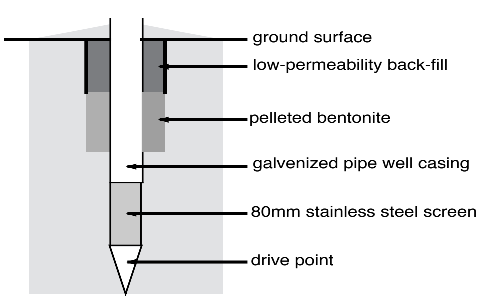

Figure 3. Groundwater well and piezometer design and installation technique.

It usually takes constructed agricultural wetlands one to three years to mature to a point where they become efficient at the removal of nitrate-nitrite (Craft, 1997). Denitrification may be slow initially as the wetland will need time to develop the physical features and the microbial community necessary to carry out its intended functions. In particular, the development of a rich-organic substratum which facilitates the anaerobic environment necessary for denitrifcation can take time to develop (Raisin and Mitchell, 1995). As evidenced by the percentage of nitrate that the Indian Lake Wetland attenuated, it is apparent that it will not take as long to mature to the point where it acts as an efficient nitrogen sink as many newly constructed agricultural wetlands. This rapid maturation suggests that it is likely that the wetland basin was already a subterranean wetland prior to the surface construction. As macrophytes become established in the open water basins, it is expected that phosphorus retention will improve due to a decrease in flow velocity, which will increase sedimentation rates. The relatively steep sides and permanence of the water-holding basins appears to prevent the flux of dissolved reactive phosphorus from soils that are exposed for significant periods of time following

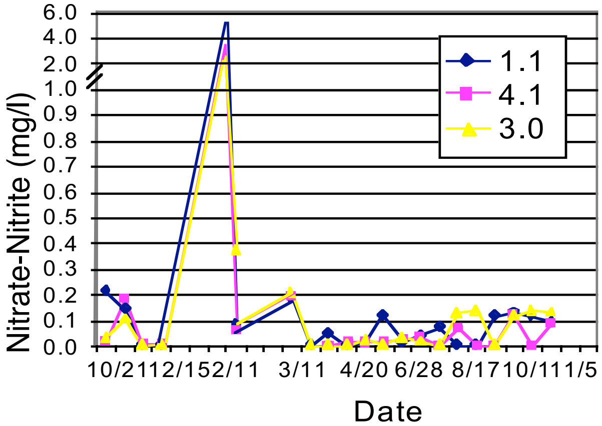

Figure 4. Concentration of nitrate-nitrite at the inflow (1.1), middle (3.0), and outflow (4.1).

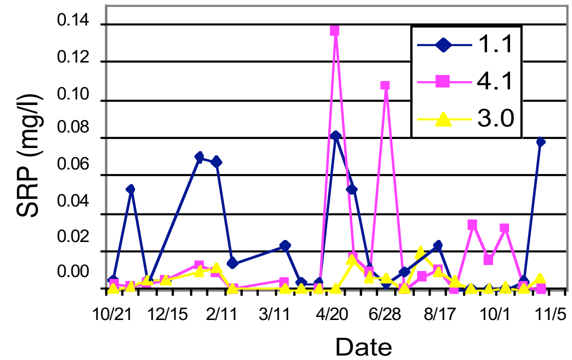

Figure 7. Concentrations of SRP at the inflow (1.1), middle (3.0), and outflow (4.1).

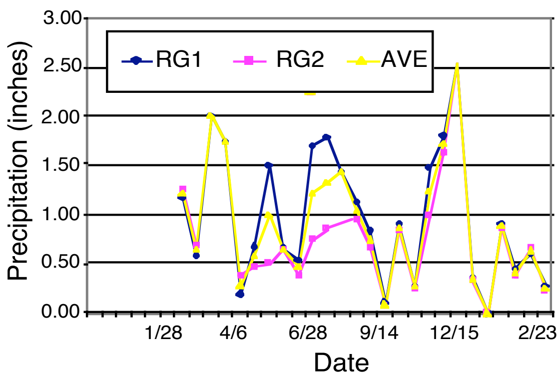

Figure 5. Precipitation during 1999. RG2 has a slow leak in it during the summer months.

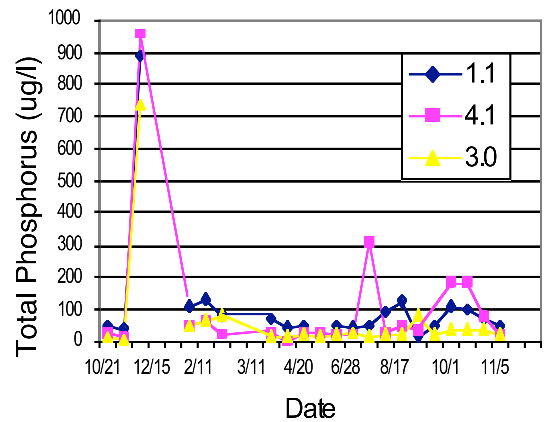

Figure 8. Concentrations of total phosphorus at the inflow (1.1), middle (3.0), and outflow (4.1).

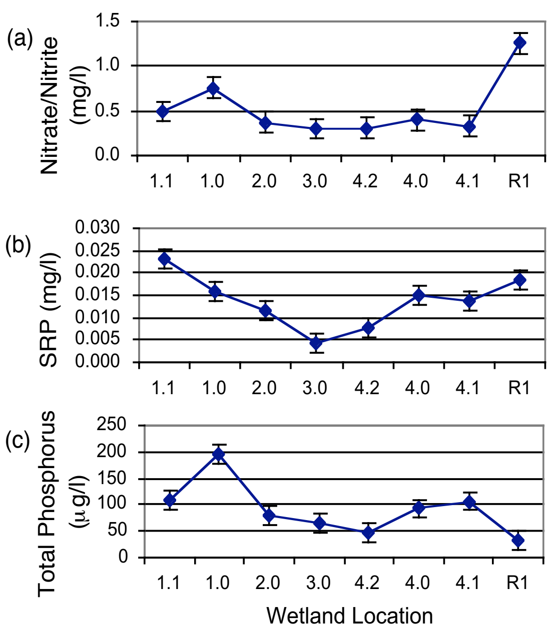

Figure 6. Concentration of (a) nitrate-nitrite, (b) SRP, and (c) total phosphate along the flow path from the inflow to the outflow of the constructed wetland in 1999.

inundation (Olila et al., 1997). Although the northern edge of Pond 3 fits this description, there was no observed increase in phosphorus further down the flow path. In the middle of December 1999, Pond 3 was drained by tunneling muskrats. It remains to be seen how this will affect phosphorus retention.

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